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(71) Applicant
The Secretary of State for Defence
(United Kingdom)
Whitehall
London SW1A 2HB

(72) Inventors
Charles Rutland Barsby
Colin Andrew Millar
Tayler

(74) Agent and/or Address for Service
N. A. Riddle,
Procurement Executive,
Ministry of Defence,
Patents 1A(4),
Room 2014,
Empress State Building,
Lillie Road,
London SW6 1TR

(54) Jet propulsion nozzle having a shroud

(57) A method and means for improving the efficiency of a jet propulsor having fluid issuing from the orifice 2 of a fluid nozzle 3 comprises attaching to the nozzle in a fluid-tight manner a cylindrical shroud 6. The length of the shroud is selected such that the shroud lip 7 is just out of contact with the issuing fluid 1. In this condition a pressure depression is experienced at the fluid orifice due to the presence of the shroud, improving the specific thrust of the propulsor. The shroud may be constructed such that its length is adjustable. In the optimum arrangement, the ratio of the cross-sectional area of the shroud to that of the nozzle orifice is about $\sqrt{2}$.

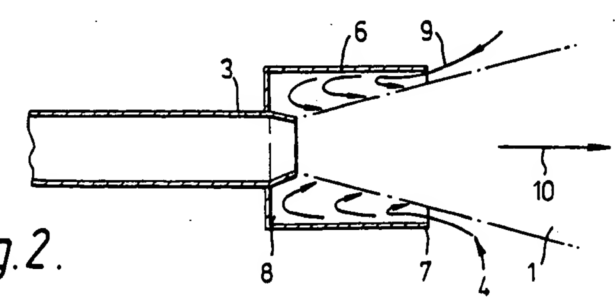

Fig.2.

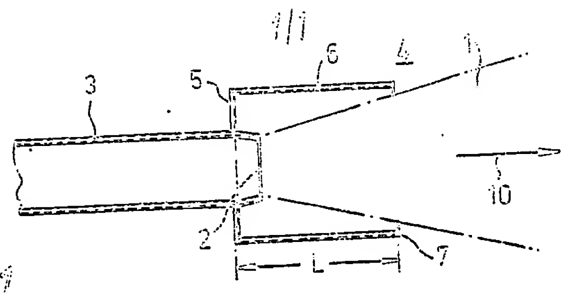

Fig.1.

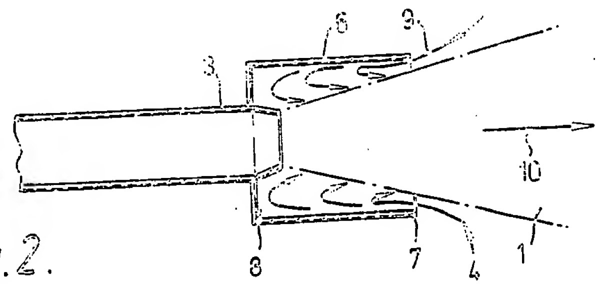

Fig.2.

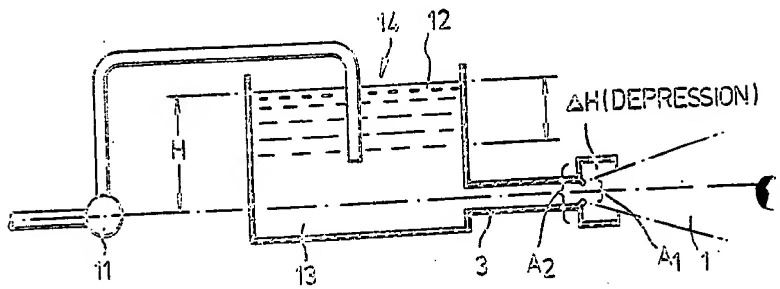

Fig.3.

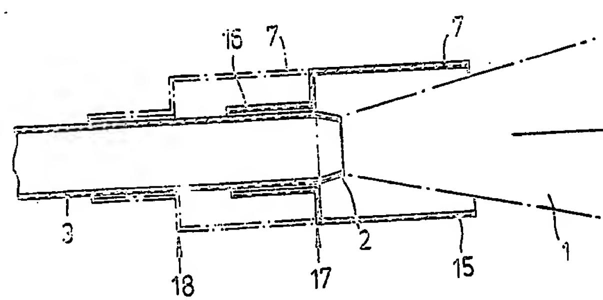

Fig.4.

SPECIFICATION

Improvements in or relating to jet propulsion systems

The invention relates to a jet propulsion system wherein a jet of fluid discharges from a nozzle and in particular to a jet propulsion system of the type used in propelling aircraft, ships and submersibles, where the propulsive jet discharges into a fluid, for example, a gas jet discharging into air, a water jet discharging into air, a water jet discharging into water, or a water jet discharging into air or gas. In such systens the thrust is obtained from the jet momentum discharging from the nozzle, the energy for which being supplied from a prime mover driving a pump, compressor, fan, or a gas turbine, or similar energy source, and it is important in the interests of fuel economy to keep fuel consumption to a minimum. Alternatively an increase in propulsive energy, and thrust may be obtained for the same fuel consumption, or energy input.

UK patent No 1582987 describes a method for augmenting the thrust of a jet propulsor by providing a cylindrical shroud surrounding a jet nozzle and attached to the body of the propulsor in an air-tight manner. The propulsive increase due to the shroud is stated to be an essential function of the length of the shroud such that when the shroud length is increased such that the lip of the shroud just touches the expanding jet flow from the nozzle the optimum conditions prevail.

The inventors, however, have found that when a shroud is used around a jet nozzle under the conditions taught in the prior art patent specification the shroud acts as an expansion diffuser and the propulsive force of the jet is not increased for the same energy input.

The object of the present invention is to provide apparatus and method for overcoming the difficultis experienced by the prior art fluid jet thrust augmenter.

The invention provides a method for improving the efficiency of a jet propulsor by directing the jet of fluid issuing from the nozzle orifice of the jet propulsor into one end of a tube or shroud of larger diameter, the one end being joined in a fluid-tight manner to the nozzle and the length of the shroud being adjusted or selected such that when in the normal operating condition of the jet propulsor the other end of the shroud is just out of contact with the fluid jet. The apparatus of the invention consists of a jet propulsor comprising a means to provide a source of high pressure fluid, the high pressure fluid being connected to a jet nozzle, one end of a cylindrical tube or shroud of diameter larger than the nozzle orifice being connected in fluid-tight manner to the nozzle and the length of the shroud being adjusted or selected such that in the normal operating condition the fluid jet discharges into the shroud and the other open end of the shroud is just out of contact with the fluid jet.

The inventors have found that when the above conditions are satisfied with a tube or shroud surrounding the propulsor nozzle, and enclosing the jet, extending downstream to a distance at which the jet approaches but does not contact the shroud lip, there is a reduction in pressure created within the shroud, causing the fluid into which the jet is discharging to enter the shroud between the jet and the shroud lip in the opposite direction to the jet flow. This prevents the jet from making contact with the shroud in the normal way. If, however, the shroud is progressively extended until this flow is excluded, then contact will be made as in the prior art arrangement, and the shroud becomes a sudden expansion diffuser. The invention achieves its optimum effect by extending the shroud just so far, that the maximum suction within the shroud is obtained without the jet contacting its wall. The inventors have shown theoretically that the suction or depression must be one half of the difference between the total and static pressure at the nozzle (dynamic head) for the gain in propulsive power, or reduction in power supplied, to be a maximum. At this condition, the effective area ratio between the nozzle (A1) and the shroud (A2), or the ratio between the nozzle velocity and the effective discharge velocity from the shroud should be $\sqrt{2}$. In the selection of shroud diameter, this is the design criterion to be aimed for, and is obtained by allowing just sufficient area ratio above $\sqrt{2}$, for the surrounding fluid into which the jet discharges, to enter the shroud lip for the purpose of preserving separation between the jet and the shroud.

Preferably when a shroud according to the invention is added to an existing jet propulsor there is provided means to extend and retract the shroud such that when the jet propulsor operates at maximum power, as for example a jet engine on take-off, the shroud is retracted. Operation of the jet propulsion system at maximum power with the shroud extended could overspeed the system and render it unsafe. Where, however, a new jet propulsor system is designed to incorporate a shroud according to the invention the capability of retracting the shroud is not necessary since the system can be designed to operate in such a way that there are no potentially damaging effects due to the presence of the shroud.

In order to achieve the optimum enhancement from use of the invention it is preferable to provide an adjustable nozzle orifice when matching a shrouded nozzle to an existing jet propulsion system. The arrangement is such that when the shroud is extended the nozzle orifice should be increased proportionally, and similarly the nozzle orifice reduced proportionally when the shroud is retracted.

In order that the invention might be better understood two arrangements are described in relation to the accompanying drawings of which:

Figure 1 is a schematic representation of a fixed shroud according to the invention;

Figure 2 shown the entrainment of the environmental fluid by the fluid jet within the shroud;

Figure 3 shows graphically the pressure head reduction due to the presence of the shroud; and

Figure 4 shows a retractable shroud for attachment to an existing jet propulsion system.

Figure 1 shows a fluid jet 1 expanding from the orifice 2 of a jet nozzle 3 into an environmental fluid 4. Attached to the nozzle 3 in fluid-tight manner at one end 5 is a cylindrical shroud 6. The shroud 6 extends downstream and its length L is chosen such that under the normal operating conditions as shown, the lip 7 of the shroud 6 is just out of contact with the fluid jet 1.

Under these conditions the fluid flow conditions are such as are shown in Figure 2. There is a reduction in pressure created within the area 8 of the shroud which causes environmental fluid 4 to enter the shroud 6 between the jet 1 and the shroud lip 7 in the opposite direction 9 to the jet flow 10. This flow in the direction 9 becomes entrained within the fluid jet 1 inside the shroud 6. The opposie flow 9 within the shroud lip 7 prevents the jet from making contact with the shroud 6 in the normal way. If the length L of the shroud 6 is increased such that the lip 7 contacts the jet flow 1 the reverse flow of the environmental fluid 4 is excluded and then the shroud 6 becomes a sudden expansion diffuser. The optimum effect is achieved by extending the length L of the shroud 6 so that the shroud lip 7 just fails to make contact with the fluid jet 1. Under these conditions a maximum suction is achieved within the shroud to augment the jet flow through the nozzle 3. Thus the reverse flow of the environmental medium into which the jet discharges in entering the shroud provides effective separation between the jet and the shroud lip, and prevents the position of thrust moving downstream from the nozzle to the shroud lip. The jet at the nozzle discharge position therefore experiences a reduction in pressure, relative to the fluid into which it discharges after the shroud.

The overall effect of this can be seen on the diagram shown in Fig 3, in which the pump H can be a compressor, fan, or gas turbine, capable of generating a fluid head of pressure H across the nozzle. The head H is repesented by the height of a fluid 12 within a container 13 open to the atmosphere at 14 and connected to the nozzle 3. With the shroud removed or retracted, the nozzle discharges into the surrounding fluid normally, and the pressure head required to produce this is from the pump alone. With the shroud positioned or extended, as described, an additional head—AH is provided, which can be used to increase propulsive power for the same energy supplied to the pump, or this can be reduced for the same propulsive power.

It is fundamental to the system, that there will always be a negative pressure thrust, produced by the suction or depression within the shroud, and this must be offset against the icreased momentum thrust produced by the jet before a net gain is attained. It is found that the suction or depression must be one half of the difference between the total and static pressure at the nozzle (dynamic head) for the gain in propulsive power, or reduction in power supplied, to be a maximum. At this condition, the effective area ratio between the nozzle A1 and the shroud A2, or the ratio between the nozzle velocity and the effective discharge velocity from the shroud should be $\sqrt{2}$. In the selection of shroud diameter, this is the design creterion to be aimed for, and is obtained by allowing just sufficient area ratio above $\sqrt{2}$, for the surrounding fluid into which the jet discharges, to enter the shroud lip, for the purpose of preserving separation between the jet and the shroud.

When the optimum effective area ratio between the nozzle and the jet at exit from the shroud is obtained, it can be shown that the increase in propulsive energy, for the same energy supplied, or the reduction in energy supplied, for the same propulsive energy will be 12½%, compared with the simple nozzle without a shroud, this being the theoretical maximum for the system.

It is considered that the most advantageous application for the shrouded jet propulsor, would be reduce fuel consumption for jet propelled vehicles, in particular aircraft, and ships. As previously stated an increased power can be obtained for the same fuel consumption, but for existing installations the advantages of fuel economy would be the greater attraction. For this purpose the shroud would be provided with a mechanical means of extension and retraction as shown in Fig 4, to enable the advantages of fuel economy to be obtained at the operating conditions required. The retractable shroud 15 is provided at the end remote from the shroud lip 7 with a fluid tight cylindrical bearing 16 which engages the outer surface of the jet nozzle and by means of which the shroud 15 can be moved between an extended position 17 and a retracted position 18. At maximum power the shroud 15 will be retracted to the position 18 to allow the jet propulsion system to operate normally ie as though there were no shroud present. This avoids overspeeding of the power source prime mover. Reference to Fig 3 illustrates this, where for example the shroud is extended and an additional pressure head created; the prime mover power source sensing a reduced load from the pump will increase speed, and therefore for a fixed throttle setting, power as well, depending upon the control system. The pump will then produce more flow and head, according to its characteristics, and those of the power source, until a new equilibrium running condition is reached. This however could well be above the maximum power and speed rating for the prime mover, and therefore even for a short duration would be unacceptable. Preferably therefore, the shroud should be retracted at maximum power ratings, or the prime mover speed controlled, which would however reduce the maximum power below that available from the simple unshrouded nozzle. The reason for this is explicit in the function of the shroud, which as previously stated creates a negative pressure thrust, opposing the momentum thrust from the increased velocity of the jet; therefore for the same thrust the jet velocity and flow for a fixed nozzle size, must be greater and the prime mover speed higher. Under normal operating conditions of the jet propulsion system the shroud 15 will extend to the position 17.

For a new design propulsion system, employing the jet shroud, however, the foregoing consideration can be accomodated by optimising the speeds of the pump and prime mover to suit; thus enabling the propulsor to operate in the normal way without the need for retracting the shroud.

Some adjustments to nozzle area is necessary, if precise matching of the shrouded nozzle to an existing jet propulsion system is to be achieved, although for a small penalty it can remain unchanged. This arises from the relationship between drag and therefore thrust, which are both proportional to the square of the jet velocity; and the ratio between vehicle velocity and jet velocity, which should remain unchanged for the same propulsive efficiency. Therefore when the jet shroud is extended, the nozzle should be increased

proportionally to keep nozzle jet velocity the same, for the same thrust. It has been found that the maximum theoretical increase in propulsive energy, which can be produced by a shroud is 12.5%, and since this is the product of thrust and jet velocity, and thrust is proportional to the square of jet velocity: the increase in jet velocity at this optimum condition is $3\sqrt{1.125}=1.04$, or 4%, and the thrust increase will be 8%. For precise matching, when the shroud is extended, it will therefore be necessary to increase nozzle area by 8%. The mechanical means of achieving variable propelling nozzle area are well established, but it may not be convenient or even possible to achieve this on an existing installation, without considerable modification. If therefore the propelling nozzle area remains unchanged, and the jet velocity increases by 4%, the propulsive efficiency will reduce by approximately 2%, giving a net theoretical maximum increase in propulsive energy of approximately 10%. This therefore is also the maximum theoretical reduction in specific fuel consumption attainable, when the shroud depression corresponding to the optimum effective area ratio, between the shroud and the propelling nozzle of $\sqrt{2}$ is attained.

The embodiments described are intended to be exemplary of the invention and modifications within the scope of the invention described thereby will be apparent to those skilled in the art.

CLAIMS

1. A method for improving the efficiency of a jet propulsor by directing the jet of fluid issuing from the nozzle orifice of the jet propulsor into one end of a tube or shroud of larger diameter, the one end being joined in a fluid-tight manner to the nozzle and the length of the shroud being adjusted or selected such that when in the normal operating condition of the jet propulsor the other end of the shroud is just out of contact with the fluid jet.

2. A method for improving the efficiency of a jet propulsor wherein the ratio between the cross-sectional areas of the shroud and the nozzle orifice is substantially equal to $\sqrt{2}$.

3. A method for improving the efficiency of a jet propulsor as claimed in claim 1 or 2 wherein the shroud is retractable such that when the jet propulsor operates at maximum power the shroud is retracted.

4. A method for improving the efficiency of a jet propulsor as claimed in claim 3 wherein the nozzle orifice is adjustable such that the diameter thereof can be varied in proportion to the length of the shroud.

5. A jet propulsor comprising a means to provide a source of high pressure fluid, the high pressure fluid being connected to a jet nozzle, one end of a cylindrical tube or shroud of diameter larger than the nozzle orifice being connected in fluid-tight manner to the nozzle and the length of the shroud being adjusted or selected such that in the normal operating condition the fluid jet discharges into the shroud and the other open end of the shroud is just out of contact with the fluid jet.

6. A jet propulsor as claimed in claim 5 wherein the ratio between the cross-sectional areas of the shroud and the nozzle orifice is substantially equal to $\sqrt{2}$.

7. A jet propulsor as claimed in claim 5 or 6 wherein the shroud is moveable to a retracted position when the jet propulsor operates at maximum power.

8. A jet propulsor as claimed in claim 7 wherein the nozzle orifice is adjustable such that the diameter thereof can be varied in proportion to the length of the shroud.

9. A jet propulsor substantially as described with reference to Figures 1 to 3 or with further reference to Figure 4 of the accompanying Drawings.

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